Effect of the PreBind engagement process on scrum timing and stability in the 2013 to 2016 Six Nations

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2017-0531.R2
Manuscript Type:	Original Investigation
Date Submitted by the Author:	n/a
Complete List of Authors:	Bradley, Edward; University of Sunderland, Sport & Exercise Hogg, Robert; University of Sunderland, Sport & Exercise Archer, David; Sunderland University, Department of Sport and Exercise Sciences
Keywords:	rugby union, scrum engagement, video analysis, duration, player welfare

Effect of the PreBind engagement process on scrum timing and stability in the 2013 to 2016 Six Nations

Original Investigation

Abstract

This study examined if changes in scrum engagement laws from the "crouch-touch-set" (CTS) in 2013 to the "PreBind" engagement from 2014 onwards have led to changes in scrum characteristics, specifically timing, in international rugby union.

Duration and outcomes were identified for all scrums occurring in the 2013-2016 Six Nations (n=60 games) using video analysis.

Scrum duration increased after the introduction of the PreBind engagement from 59 s in 2013 to 69 s in 2016 (ρ=0.024, ES 0.93). A significant increase in mean contact duration per scrum occurred when prebinding was adopted (ρ<0.05), moving from 7.5 s under the CTS process to 8.5, 10.0 and 10.8 s with PreBind in 2014, 2015 and 2016 (ES 0.71, 2.05 and 3.0, respectively). The number of scrum resets and collapsed scrums, along with early engagement and pulling down infringements were lower under the PreBind process.

Overall, the PreBind engagement resulted in longer scrums with significant increases observed in overall and contact durations, with improved stability related characteristics. The longer contact time is a consequence of increased stability with a shift from high energy impact to a sustained push phase with a lower force that is a benefit to player welfare.

Keywords: rugby union; scrum engagement; video analysis; duration; player welfare

Introduction

Rugby Union is one of the most popular team sports in the world. As a collision based team game, a high incidence of injury has been reported (Haseler, Carmont, & England, 2010; Roberts, Trewartha, England, Shaddick, & Stokes, 2013). The scrum is a means of restarting the game in rugby after an infringement has occurred, with an average of 18.8 scrums per game occurring at English Premiership club level (Taylor, Kemp, Trewartha, & Stokes, 2014). A scrum is defined by the formation of two opposing sets of eight forwards, creating a channel into which the scrumhalf feeds the ball that is moved towards the back of the scrum, where the scrumhalf can recollect the ball and open play resumes. The scrum is formed through the engagement of opposing front rows with the remaining forward players positioning themselves behind in two further rows. Scrum forces occurring between the front row players on engagement of between 7.2 kN (Quarrie & Wilson, 2000) and 8 kN (Milburn, 1990) during machine scrummaging indicate the potential high intensity nature of the scrum. More recently Cazzola, Preatoni, Stokes, England, and Trewartha (2014) have shown that the average impact force is between 6.3 kN and 9.8 kN in live 3x3 or full scrums, while Cazzola, Hosgrove, Preatoni, Gill and Trewartha (2017) produced estimated compressive impact forces of between 1.2 and 1.8 kN each, across the individual upper torso locations of the thorax, right and left clavicles and scapulae in a simulated whole-body OpenSim model. Large impact forces, coupled with the repetitive nature of the scrum and likelihood of collapse (Quarrie, Cantu, & Chalmers, 2002) are a risk factor for cervical spine injury. Two mechanism are currently proposed; Buckling producing bilateral facet dislocations at lower cervical spine levels (Kuster, Gibson, Abboud, & Drew 2012) and hyperflexion producing facet joint contact and flexion at the intervertebral joint beyond the structural integrity resulting in dislocation (Dennison, Macri, &

Cripton, 2012); though the true mechanism is not fully understood, primarily due to the significant challenges, both physically and ethically, in examining catastrophic injury mechanisms in rugby. Whilst the incidence of injuries occurring at the scrum are low in comparison to other phases of play, with 5.8 injuries per 1000 player hours being attributed to the scrum phase (Fuller, Brooks, Cancea, Hall & Kemp, 2007), they account for a larger number of serious or catastrophic injuries. Thus, scrums are a cause of concern for the health and wellbeing of the players (Bourke, 2006; Fuller et al., 2007; Gianotti, Quarrie, & Hume, 2009).

To reduce the high impact forces, changes in the engagement process have been implemented over recent seasons by World Rugby (formally International Rugby Board (IRB)). From 2007, engagement was a four-stage process of crouch-touch-pause-engage (CTPE) that allowed the front rows to squat a fixed distance apart and on the engage command, crash together. This resulted in a collision between the opposing teams where winning the contest was primarily due to greater force development. Preatoni, Stokes, England, and Trewartha (2015) reported peak impact forces of 16.5kN with the CTPE process. Additionally, there was less control with an increased number of collapsed scrums thereby increasing the risk of injury (Roberts, Trewartha, England & Stokes, 2015) with double the incidence of injury shown to occur in scrums that did collapse (8.6 per 1000 scrum events), compared to those that did not collapse (4.1 per 1000 scrum events; Taylor et al, 2014). In an attempt to depower the scrum, new engagement processes have been established. The three-stage crouch-touch-set (CTS) process was introduced at the beginning of the 2012/13 season. A further change was implemented for the 2013/14 season with the touch command replaced with bind (PreBind) in a further attempt to remove the hit by limiting the distance between the front rows. The PreBind process has been shown to significantly reduce peak loading

95 across the front-row players during live scrummaging by 35% compared to CTPE and
96 25% to CTS (Cazzola, Preatoni, Stokes, England, & Trewartha, 2015) as the players
97 engage in a more controlled manner through a significantly smaller pre-engagement
98 distance. Additionally, Cazzola et al. (2014) examined the effectiveness of these two
99 three-stage engagement process in 54 forward packs and found reduced vertical centre
100 of mass and shoulder movement that is indicative of a more stable scrum in the PreBind
101 engagement compared to CTS, which hopefully reduces the risk of scrum collapse thus
102 improving player safety.

103 The immediate effect of the engagement law change on scrum performance outcomes
104 has been examined by Stean, Barnes and Churchill (2015). A significant increase in
105 the number of reset scrums from the 2012-13 to the 2013-14 English Premiership
106 season, that more than doubled from 3.9 to 8.2 per match and an increase in the number
107 reset scrums as a result of collapse increased from 2.0 to 4.5. The two seasons
108 examined by Stean bridges the law change from the CTS to PreBind and indicate that
109 the new protocol has not improved the stability during live scrummaging and this is
110 contradictory to the findings of Cazzola et al (2014) and Preatoni et al (2015) that were
111 the drivers for the introduction of the new engagement process. However, the data
112 collected by Stean et al (2015) is from a sub-selection of matches during each season
113 that may not be reflective of the effect of the law change across the whole of the
114 competition, nor do they consider the longer-term effect of player education and
115 training with the new engagement. These law changes have been based on the
116 assessment of scrum biomechanics related to reducing the initial impact force, thereby
117 decreasing the risk of injury and improving player safety (Trewartha, Preatoni,
118 England, & Stokes, 2015) that may shift the focus of the scrum to the push phase.
119 Thus, the aim of this study was to determine if the changes in scrum engagement laws

have led to changes in scrum characteristics, specifically timing and stability, in international rugby union. It is hypothesised that changes would result in longer contact durations and a reduction in the number of reset or collapsed scrums, due to a more controlled engagement.

Methods

Study design and sample:

The Six Nations Championship (hereafter called Six Nations) is the primary international tournament in the Northern Hemisphere and is contested by the six Tier One rugby nations in Europe. All games from the 2013-2016 Six Nations competitions were included for analysis using free-to-air BBC and ITV broadcasts of the games. A total of 60 games were analysed (15 per tournament). These four years were chosen as it covered the initial effect of the change from the CTS engagement process to the PreBind, with two subsequent years of the PreBind process to assess if familiarity through player education and training with the PreBind process improved outcomes (PreBind+1 and PreBind+2). The engagement processes were: 2013: CTS; 2014-2016: PreBind. Ethical approval was obtained from the University of Sunderland ethics committee.

Study Procedure:

Each game was recorded using a VirginMedia TiVo box and subsequently viewed by an experienced rugby analyst. Coding of each game was completed using a bespoke Microsoft Excel spreadsheet report. Notational measures of scrum timing and contact timing were recorded with all timing taken from the TV match clock displayed in the upper corner of the screen. For each match, total number of scrum events, individual scrums and individual scrum contacts were summed. A scrum event was defined as the

point from the initial referee whistle signal of a scrum until the successful completion of the scrum or the award of a free kick or penalty, whereas a scrum was defined as the signal of a scrum until the end of the process through an outcome which ends the scrum This includes the ball re-entering open play via the scrum-half or number eight picking the ball out of the scrum or an event where the referee resets the scrum for the process to be repeated, such as collapse. Scrum contact was defined as the time between the referee calling the engagement command 'set' or 'bind' until disengagement of the front-rows was observed. Total and mean scrum event and scrum count and duration were calculated, along with total scrum contact time and mean scrum contact duration. Collapsed and reset scrums, along with early engagement and pulling the scrum down infringements were identified as indicators of scrum stability and the total number per game were recorded. All decisions were based on the verbal commands or hand signals of the referee.

Data analysis:

To assess the reliability of observer measurements, three games per year were re-analysed two weeks subsequent to the first analysis. Intraclass correlation coefficients were calculated and intra-observer agreement was rated as excellent if the value was >0.8 (Atkinson & Nevill, 1998). All variables displayed values of between 0.91 and 0.98. Measurements were compiled for each Six Nations competition and descriptive statistics (totals, means and standard deviations) were calculated for each year. Normality of the data were assessed using a Shapiro-Wilk Test to identify further analysis. To determine if the PreBind engagement process improved scrum performance compared to the CTS process, parametric outcome measures were analysed using a one-way ANOVA with an LSD post hoc test with year as the independent variable, while a Kruskal-Wallis test was used for non-parametric

measures. All statistical tests were ran using SPSS v23 (IBM Statistics, NY) with significance set at $\rho<0.05$. Magnitude based inferences were determined by calculating the effect size (ES) of differences in the pooled means of temporal and performance variables between each year. The magnitude of the ES was classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0) (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results

Scrum frequency and timings

Scrum frequency and timings are given in Tables 1 and 2 and Figure 1. While initially the number of scrum events per game (Figure 1A) and total time per game spent scrummaging displayed a non-significant trend towards decreasing (13.4, 11.7, 11.6 and 790, 723, 736 s respectively) after the 2013 Six Nations, the total time spent at the scrum was significantly longer (917 s) in the 2016 competition compared to 2014 and 2015 (Figure 1B). Additionally, although the mean time per scrum event did not differ between 2013, 2014 or 2015 tournaments (59, 63, 63 s, respectively), it was significantly longer in 2016 (68 s) (Figure 1C). Completion of scrums accounted for 15-19% of the total game time, with significantly longer contact durations in 2016 compared to all other years (Figure 1G). Similar trends were also found for the duration of scrums (Figure 1E) and scrum contact. A significant increase in mean contact duration per scrum occurred when prebinding was adopted ($\rho<0.05$), moving from 7.5 s in 2013 under the CTS process to 8.5, 10.0 and 10.8 s in 2014, 2015, and 2016 with PreBind engagement (ES 0.71, 2.05 and 3.0, respectively) (Figure 1H).

Scrum outcomes

The number of scrums being reset did not significantly differ over the years in question, though small decreases were observed in the initial two years of the PreBind engagement process (Table 1 and Figure 2). Between 29-35% of all scrums ending in collapse, but only trivial to small differences in the number of collapsed scrums were observed across the four seasons. Significant reductions in the number of early engagement infringements were seen after the adoption of the PreBind process, though the magnitude of this change diminished over time (ES -1.75, -1.31, -1.06 for PreBind, PreBind+1 and Prebind+2, respectively). The number of front-rows penalised for pulling down the scrum was significantly lower in both the initial PreBind engagement (ρ=0.023, ES -0.98) and post one year (ρ=0.045, ES -0.88), and tended to be lower in 2016 (ρ=0.081, ES -0.79).

Discussion

The aim of the study was to determine if the changes in scrum engagement laws have led to changes in scrum characteristics by analysing the frequency, timing and outcome of scrums in the Six Nations championship between 2013 and 2016. The four years were chosen as it covered the initial effects of two implementations of the engagement process, CTS in 2013 and PreBind in 2014. A further two years (2015 – PreBind+1; 2016 – PreBind+2) were also included in the analysis to examine if familiarisation through player education and training with the PreBind engagement had any effect on scrum performance. Initially, the total number and overall duration of scrums events reduced after the introduction of the PreBind engagement. However, this trend was reversed in the 2016 competition, with the total time increasing by 127 s (ES 0.60) and mean scrum event duration by 10 s (ρ=0.024, ES 0.93). Scrum contact duration increased significantly year on year after prebinding was adopted (ρ<0.05), moving from 7.5 s under the CTS process to 10.8 s with PreBind in 2016 (ρ=0.002, ES 1.26).

Scrum resets and number of collapsed scrums were unaffected by the change in scrum engagement with no significant changes between the four years.

A combination of tactical play, large engagement forces (Cazzola et al., 2014; Quarrie & Wilson, 2000) and stability issues (Cazzola et al., 2015) increase the likelihood of incorrect scrum formation, collapse and resetting. In the current study, the duration of each individual scrum increased year on year, with a significantly longer scrum duration in 2016 compared to the CTS process. Overall, the total game time spent involved in scrums initially reduced by 8% from 790 seconds to 723 seconds after the introduction of the PreBind process, though this can be attributed to a reduction in the mean number of scrums per game by 1.7. However, the number of scrums in 2016 was the same as in 2013 and the total time was 16% greater (917 secs). Scrum contact time was significantly longer under the PreBind engagement and increased each year from 7.5 to 10.8 seconds, an overall increase of very large magnitude (44%, ES 3.0). Preatoni et al. (2015) reported sustained push forces in machine scrummaging with an international pack of 8 kN under the CTS process compared to 15.8 kN during engagement. Similarly, Cazzola et al. (2015) have shown that peak impact forces occurring under the PreBind process are 25% lower than the CTS engagement; the average forces exerted during the sustained push phase were 37% lower. Thus, the reduced initial impact with the PreBind process combined with a longer period of scrummaging at a lower intensity in live game scrums reflects a safer scrum situation by placing reduced stress on the players during the dynamic loading phase of the scrum. Injury risk from dynamic impacts is greater due to the higher force and greater rate of force development produced on contact at engagement, with Winklestein and Myers (1997) stating that cervical spine injury occurs within 2-20 ms of impact and Cazzola et al (2015) identifying peak impact forces within the first 0.5 seconds. It is

uncertain if this will prevent hyperflexion (Dennison et al., 2012) or buckling (Kuster et al., 2012) mechanisms of injury, especially if a misdirected load is involved (Silvestros & Cazzola, 2017). Despite this, decreasing the load occurring during this phase potentially reduces the likelihood of cervical spine injury, as proposed by Torg, Vegso, O'Neill, and Sennett (1991), producing a safer scrum scenario.

The findings of the current study differ from those of Stean et al. (2015), who reported a significant increase in the number of scrums, resets and collapsed scrums in the English Premiership in the initial season after the introduction the PreBind process. Various factors may account for this including playing level, refereeing mentality and data collection approach. As the Premiership is a domestic competition, there will likely be a greater variability in skill level and physical ability than those performing in the Six Nations and may account for the observed differences, although existing research shows no differences in the magnitudes of forces being developed in the scrum between 'international' and 'elite' rugby forwards (Preatoni, Stokes, England, & Trewartha, 2013). Additionally, the present study represents all games from four championships, whereas Stean and colleagues (2015) selected a sample of 20 games from 4 weeks over two seasons. This may not have been representative of the whole season as it does not account for changes in playing condition or styles, something the authors do acknowledge, and as a result the findings may overestimate the mean outcome numbers.

Practical Applications

Whilst the PreBind engagement significantly increased the length of the scrum contact, the majority of this occurs as a quasi-static load experienced during the sustained push phase. This indicates a lower risk and therefore a positive outcome for player welfare at the elite level in rugby union. However, the conditioning requirements of both

267 increased mean (44%) and total scrum contact duration (37%) must be considered in
268 terms of player preparation. Changes in scrum contact time due to the PreBind
269 engagement introduction is represented as an increase in the steady-state push phase of
270 the scrum. This longer quasi-static loading condition changes the physiological and
271 biomechanical demands placed on the players, especially the front-row. Recent
272 research found that fatigue resulting from repeated scrums increased fluctuations in
273 force amplitude in the knee extensors, particularly during the sustained pushing phase
274 (Morel & Hautier 2016). Coaches may need to consider additional strength and
275 conditioning training focused on meeting the increased demand placed on each players'
276 musculoskeletal system during the longer scrums, specifically the sustained contact
277 phase, to continue to improve performance and help towards player welfare.

278 Whilst the primary driver for scrum engagement law changes has been in reduction in
279 the impact forces, it was also shown that the PreBind engagement decreased the
280 distance between the opposing front rows and reduced the vertical displacement and
281 forces occurring (Cazzola et al., 2014) and theoretically reducing the likelihood of the
282 scrum collapsing. The number of collapsed scrums did not significantly differ across
283 the years investigated and this indicates that the stability of the scrum has been
284 maintained after the introduction of the PreBind engagement process. Indeed, the
285 tendency for a slight reduction in collapsed scrums in the two years following the
286 introduction of the PreBind, combined with the significant reduction in stability related
287 scrum infringements (early engagement and, pulling down the scrum) are further
288 indications that the new process is beneficial. It is possible that packs have required
289 time to fully learn the PreBind engagement and this may explain initial increases in
290 collapsed scrums followed by year on year decreases that support the role of player
291 education and training. This is important as rule changes are often implemented in pre-

season, giving little time for players to effectively learn and master the new techniques. The Six Nations takes place in February and March, half way through the Northern Hemisphere season and the 2014 competition was only 7 months after the introduction, while the following tournaments allowed a further 12 and 24 months of training and skill development.

The Six Nations is the premier international competition in the Northern Hemisphere and participating countries have a playing style dissimilar to the Southern Hemisphere and thus the findings of the current study are limited by this. A future study should focus on identifying the effects of the PreBind engagement process on scrum characteristics relating to the safety and stability in the Rugby Championship or Super Rugby tournaments. The current study utilised the free-to-air television broadcasts of the games as the source for analysis. Due to changing camera angles outside the control of the research team, there is potential to lose visual focus on the scrum or miss the referee calls. Whilst this did not occur in the current study, it may be an issue if this approach is adopted in future studies. The fact that all scrums events were observable and high reliability values of between 0.91 and 0.98 were calculated in the identification of temporal and outcome characteristics support this approach, especially as it enables the analysis of elite level international competition that may not be possible using conventional research approaches due to the restriction on access in national sports stadia.

Conclusions

The aim of this study was to identify if changes in the scrum engagement laws and subsequent familiarisation with the new laws affected the timing and outcome of scrums in the Six Nations. The rule changes were designed to reduce impact forces and increase stability to improve player welfare. This study found that initially the total

duration of scrums decreased after the introduction of the PreBind engagement as a result of a lower number of scrums per game, but in the third year of this new process the duration had increased above the CTS engagement. A significant yearly increase in contact time per scrum occurred, which may be due to increased scrum stability with prebinding, resulting in a longer push phase required during the scrum. The reduced dynamic impact force and extended low-load phase potentially reduces injury risk during the scrum by decreasing the biomechanical stresses experienced by the players as described in previous studies. This was further enhanced by year on year significant reductions in early engagement and pulling down infringements that are indicative of a more stable scrum. Whilst there is a non-significant decrease in collapsed scrums between 2013 and 2016, it indicates an encouraging trend that should be monitored further. Overall, the introduction of the PreBind scrum engagement process is likely to have had a positive effect on player welfare at the elite level during the international Six Nations tournament.

Acknowledgments

Funding: None. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests: All authors have no relationships with any companies that might have an interest in the submitted work in the previous 3 years and have no non-financial interests that may be relevant to the submitted work.

Ethical approval: Ethical approval was obtained from University of XX ethics committee

All authors have had full input into the work and had unrestricted access to the data. All authors take full responsibility for the integrity and accuracy of the data. The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

References

Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med.* 1998;26(4):217-238.

Bourke JB. Rugby union should ban contested scrums. *BMJ.* 2006;332:1281.

Cazzola D, Holsgrove TP, Preatoni E, Gill HS, Trewartha G. Cervical Spine Injuries: A Whole-Body Musculoskeletal Model for the Analysis of Spinal Loading. *PLOS One*, 2017;12:e0169329. doi:10.1371/journal.pone.0169329.

Cazzola D, Preatoni E, Stokes KA, England MH, Trewartha G. Does a modified rugby scrum engagement process improve the stability of the scrum and minimise the likelihood of scrum collapse? *Br J Sports Med*. 2014;48(7):577-578.

Cazzola D, Preatoni E, Stokes KA, England ME, Trewartha G. A modified prebind engagement process reduces biomechanical loading on front row players during scrummaging: a cross-sectional study of 11 elite teams. *Br J Sports Med.* 2015;49(8):541-546. doi: 10.1136/bjsports-2013-092904.

Dennison CR, Macri EM, Cripton PA. Mechanisms of cervical spine injury in rugby union: is it premature to abandon hyperflexion as the main mechanism underpinning injury? *Br J Sports Med.* 2012;46:545-549. doi:10.1136/bjsports-2012-091257.

Fuller CW, Brooks JHM, Cancea RJ, Hall J, Kemp SPT. Contact events in rugby union and their propensity to cause injury. *Br J Sports Med.* 2007;41(12):862-867.

Gianotti SM, Quarrie KL, Hume PA. Evaluation of RugbySmart: a rugby union community injury prevention programme. *J Sci Med Sport.* 2009;12(3):371-375. doi: 10.1016/j.jsams.2008.01.002.

384 Haseler CM, Carmont MR, England M. The epidemiology of injuries in English youth
385 community rugby union. *Br J Sports Med.* 2010;44(15):1093-1099.
386 doi:10.1136/bjsm.2010.074021

387 Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies
388 in sports medicine and exercise science. *Med Sci Sports Exerc.* 1999;41(1):3-13.

389 Kuster D, Gibson A, Abboud R, Drew T. Mechanisms of cervical spine injury in rugby
390 union: a systematic review of the literature. *Br J Sports Med.* 2012;46:550-554

391 Milburn PD. The kinetics of rugby union scrummaging. *J Sports Sci.* 1990;8(1):47-60.

392 Morel B, Hautier CA. The neuromuscular fatigue induced by repeated scrums generates
393 instability that can be limited by appropriate recovery. *Scand J Med Sci Sports.* 2016;22
394 doi: 10.1111/sms.12646.

395 Preatoni E, Stokes KA, England ME, Trewartha G. The influence of playing level on
396 the biomechanical demands experienced by rugby union forwards during machine
397 scrummaging. *Scand J Med Sci Sports* 2013;23(3):e178-184.

398 Preatoni E, Stokes KA, England ME, Trewartha G. Engagement techniques and playing
399 level impact the biomechanical demands on rugby forwards during machine-based
400 scrummaging. *Br J Sports Med.* 2015;49(8):520-528. doi: 10.1136/bjsports-2013-
401 092938.

402 Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and
403 spinal cord. *Sports Med.* 2002;32:633–653.

404 Quarrie KL, Wilson BD. Force production in the rugby union scrum. *J Sports Sci.*
405 2000;18(4):237-246.

406 Roberts SP, Trewartha G, England M, Shaddick G, Stokes KA. Epidemiology of
407 timeloss injuries in English community-level rugby union. *BMJ Open.* 2013;3:e003998.
408 doi:10.1136/bmjopen-2013-003998

409 Roberts SP, Trewartha G, England M, Stokes KA. Collapsed scrums and collision
410 tackles: what is the injury risk? *Br J Sports Med.* 2015;49(8):536-540.

411 Silvestros, P, Cazzola, D. Cervical spine injuries in rugby union scrummaging: Is
412 buckling the most likely injury mechanism? XVI International Symposium on
413 Computer Simulation in Biomechanics, Brisbane, Australia, July 20th-22nd 2017.

414 Stean D, Barnes A, Churchill SM. Effect of the 'Crouch, Bind, Set' engagement routine
415 on scrum performance in English Premiership Rugby. *Int J Perf Analy Sport.*
416 2015;15(3):1202-1212.

417 Taylor AE, Kemp S, Trewartha G, Stokes KA. Scrum injury risk in English
418 professional rugby union. *Br J Sports Med.* 2014;48(13):1066-1068. doi:
419 10.1136/bjsports-2013-092873

420 Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic,
421 biomechanical, and cinematographic analysis of football-induced cervical spine trauma.
422 *Am J Sports Med.* 1990;18:50-57.

423 Trewartha G, Preatoni E, England ME, Stokes KA. Injury and biomechanical
424 perspectives on the rugby scrum: a review of the literature. *Br J Sports Med.*
425 2015;49(7):425-433. doi: 10.1136/bjsports-2013-092972

426 Winklestein B, Myers B. The biomechanics of cervical spine injury and implications
427 for injury prevention. *Med Sci Sports Exerc.* 1997;29:246-255.

428

Figure 1: Variation in scrum frequency and scrum timing over the 2013 to 2016 Six Nations: A – Scrum event count; B – Scrum event total duration; C – Scrum event mean duration; D – Scrum count; E – Scrum mean duration; F – Scrum contact count; G – Scrum contact total duration; H – Scrum contact mean duration. (• indicates each individual data point; ◆ indicates the seasonal mean, dashed line is representative of the linear trend across the four years, where engagement processes are: 2013 - CTS, 2014-16 - PreBind).

Figure 2: Variation in mean frequency of stability scrum characteristics over the 2013 to 2016 Six Nations: Left-to-right key – 2013 CTS; 2014 PreBind; 2015 PreBind+1; 2016 PreBind+2. Mean count ± SD error bars presented, * indicate significant ($\rho<0.05$) decrease compared to CTS.

455 Table 1: Differences in mean scrum timing and outcome measures per game between
456 the Six Nations tournaments

Variable	2013 (CTS)		2014 (PreBind)		2015 (PreBind+1)		2016 (PreBind+2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Scrum Event (count)	13.4	2.6	11.7	2.7	11.6	2.3	13.4	2.9
Scrum Event Total Duration (secs)	789.7	179.9	722.9	158.5	736.2	215.7	917.0[bc]	242.7
Scrum Event Mean Duration (secs)	59.0	9.0	63.0	12.5	63.0	11.2	68.3[a]	10.8
Scrum (count)	17.1	4.3	14.9	3.3	14.8	3.4	17.3	4.3
Scrum Mean Duration (secs)	47.0	6.8	48.0	6.8	49.2	6.1	53.4[a]	7.4
Scrum Contact (count)	16.9	4.3	14.7	3.3	14.5	3.3	16.5	4.5
Scrum Contact Total Duration (secs)	128.0	36.1	126.0	42.9	145.3	40.4	175.9[abc]	40.2
Scrum Contact Mean Duration (secs)	7.5	1.0	8.5[a]	1.7	10.0[ab]	1.4	10.8[ab]	1.2
Reset	4.2	2.2	3.5	2.0	3.1	2.0	3.8	2.2
Collapsed	4.7	2.8	5.2	3.0	4.3	2.3	4.0	2.1
Early Engagement	1.7	1.1	0.2[a]	0.6	0.5[a]	0.6	0.7[a]	0.8
Pulling Down	0.9	1.1	0.1[a]	0.3	0.1[a]	0.4	0.2	0.4

457 [a]Significantly different from CTS process; [b]Significantly different from PreBind ($\rho<0.05$); [c]Significantly
458 different from PreBind+1 ($\rho<0.05$)

459

Table 2: Inferential differences in scrum timing and outcome measures per game in the Six Nations tournaments

Variable	CTS – PreBind		CTS – PreBind+1		CTS – PreBind+2		PreBind – PreBind+1		PreBind – PreBind+2		PreBind+1- PreBind+2	
	Effect Size	ρ value	Effect Size	ρ value	Effect Size	ρ value	Effect Size	ρ value	Effect Size	ρ value	Effect Size	ρ value
Scrum Event (count)	-0.64*	0.09	-0.75*	0.06	0.00	1.00	-0.05	0.89	0.60[#]	0.09	0.70[‡]	0.06
Scrum Event Total Duration (secs)	-0.39	0.37	-0.27	0.47	0.60*	0.09	0.07	0.86	0.95[#]	0.01[b]	0.79[‡]	0.02[c]
Scrum Event Mean Duration (secs)	0.39	0.30	0.39	0.33	0.93*	0.02[a]	-0.02	0.95	0.43	0.21	0.48	0.19
Scrum (count)	-0.56	0.14	-0.59	0.11	0.05	0.89	-0.04	0.93	0.61[#]	0.10	0.64[‡]	0.09
Scrum Mean Duration (secs)	0.28	0.44	0.34	0.38	0.89*	0.01[a]	0.04	0.92	0.62[#]	0.08	0.61[‡]	0.10
Scrum Contact (count)	-0.59	0.12	-0.64*	0.09	-0.09	0.78	-0.06	0.89	0.47	0.20	0.52	0.15
Scrum Contact Total Duration (secs)	-0.04	0.91	0.46	0.23	1.26*	0.01[a]	0.47	0.19	1.20[#]	0.00[b]	0.76[‡]	0.04[c]
Scrum Contact Mean Duration (secs)	0.71*	0.05[a]	2.05*	0.00[a]	3.00*	0.00[a]	0.96[#]	0.01[b]	1.56[#]	0.00[b]	0.61[‡]	0.11
Reset	-0.32	0.39	-0.50	0.17	-0.18	0.61	-0.20	0.61	0.13	0.73	0.32	0.39
Collapsed	0.18	0.81	-0.13	0.78	-0.27	0.57	-0.33	0.60	-0.46	0.33	-0.15	0.65
Early Engagement	-1.75*	0.00[a]	-1.31*	0.01[a]	-1.06*	0.01[a]	0.55	0.15	0.67[#]	0.08	0.19	0.78
Pulling Down	-0.98*	0.02[a]	-0.88*	0.05[a]	-0.79*	0.08	0.19	0.78	0.38	0.54	0.18	0.78

[a]Significantly different from CTS process; [b]Significantly different from PreBind (ρ<0.05); [c]Significantly different from PreBind+1 (ρ<0.05); [*]Moderate/Large effect size from CTS process; [#]Moderate/Large effect size from PreBind; [‡]Moderate/Large effect size from PreBind+1

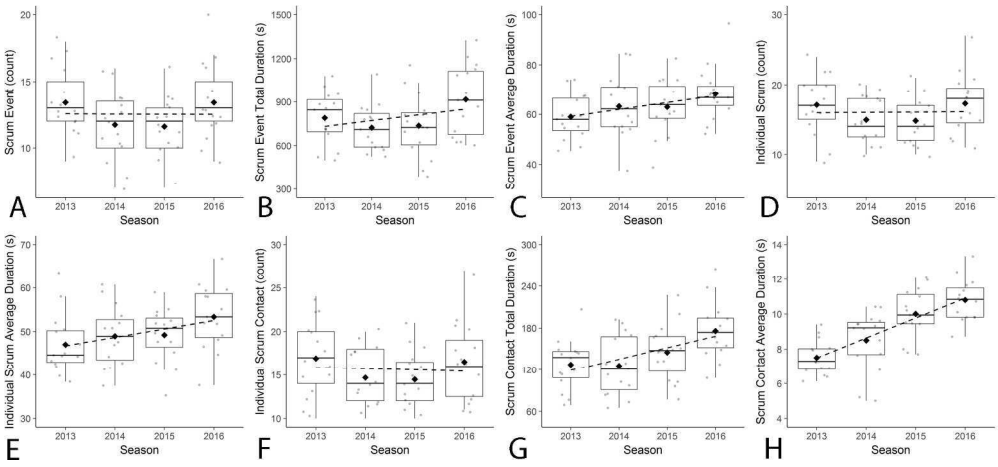

Figure 1: Variation in scrum frequency and scrum timing over the 2013 to 2016 Six Nations: A – Scrum event count; B – Scrum event total duration; C – Scrum event mean duration; D – Scrum count; E – Scrum mean duration; F – Scrum contact count; G – Scrum contact total duration; H – Scrum contact mean duration. (• indicates each individual data point; υ indicates the seasonal mean, dashed line is representative of the linear trend across the four years, where engagement processes are: 2013 - CTS, 2014-16 - PreBind).

209x96mm (300 x 300 DPI)

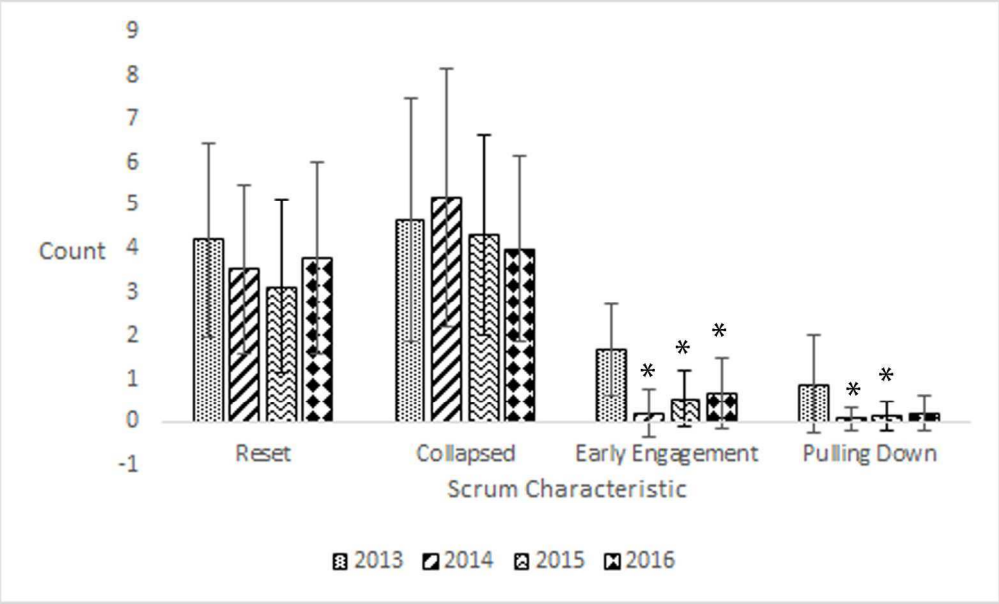

Figure 2: Variation in mean frequency of stability scrum characteristics over the 2013 to 2016 Six Nations: Left-to-right key – 2013 CTS; 2014 PreBind; 2015 PreBind+1; 2016 PreBind+2. Mean count ± SD error bars presented, * indicate significant ($\rho<0.05$) decrease compared to CTS.

165x99mm (300 x 300 DPI)